Optoelectronic Response of Multilayer CuO/NiO Nanostructures Fabricated with Different Particle Size Ranges

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Abstract
In this work, multilayer structures were fabricated from two semiconducting metal oxide (CuO and NiO) nanostructures on glass substrates by thermal evaporation method. The crystalline structures and surface morphologies of the prepared structures were determined. The effects of particle size on the optoelectronic response of CuO/NiO/glass multilayer nanostructures were introduced and analyzed. It was found that the optoelectronic response of these structures was highly stable as the particle size of the used nanomaterials was ranging in 10-100nm.

Keywords: Optoelectronic response; Copper oxide; Nickel oxide; Multilayer structures
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1. Introduction

Multilayer structures (such as CuO/NiO) have garnered significant attention in optoelectronics due to their unique electronic and optical properties [1,2]. These structures exhibit a strong optoelectronic response, primarily because of the complementary properties of CuO (p-type) and NiO (n-type) semiconductors [3,4]. The heterojunction formed between CuO and NiO layers facilitates efficient charge separation and transport, which is crucial for optoelectronic devices such as photodetectors, solar cells, and light-emitting diodes [5-8]. The band alignment at the CuO/NiO interface enhances light absorption across a broad spectrum, from ultraviolet to visible regions, making these structures highly efficient in converting light into electrical signals [9-12]. Additionally, the multilayer configuration allows for tunable bandgap engineering, enabling the optimization of optical and electronic properties for specific applications [13,14].

Metal oxide nanostructures, such as ZnO, TiO_2, CuO, and NiO, offer several advantages in optoelectronics and photonics. Their wide bandgaps and high exciton binding energies make them suitable for UV photodetection and light emission [15-18]. These materials exhibit excellent chemical stability, high transparency in the visible range, and tunable electrical properties, which are essential for transparent conductive oxides used in displays and solar cells [19-23]. The nanostructured forms of these materials, such as nanowires, nanorods, and nanoparticles, provide a large surface-to-volume ratio, enhancing light absorption and charge carrier collection efficiency [24,25]. Furthermore, metal oxides are abundant, cost-effective, and environmentally friendly, making them ideal for large-scale optoelectronic applications [26,28].

In this research, the effects of particle size on the optoelectronic response of CuO/NiO multilayer nanostructures were introduced and analyzed.

2. Experimental Part

CuO/NiO multilayer structures can be prepared on glass substrates using the thermal evaporation method (Fig. 1). Initially, high-purity CuO and NiO powders are evaporated sequentially in a vacuum chamber, depositing alternating layers on the substrate. The thickness of each layer is controlled by monitoring the deposition rate. The prepared multilayers are then annealed to enhance crystallinity and interfacial properties.

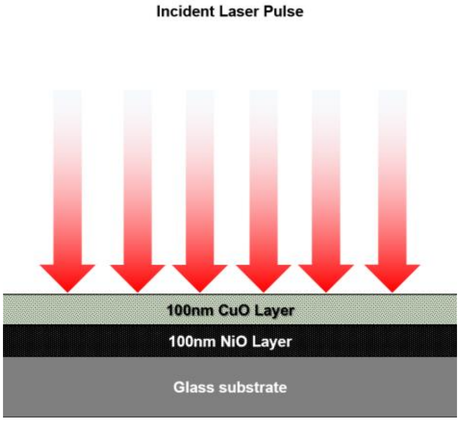

Fig. (1) Schematic diagram of the CuO/NiO multilayer structure prepared in this work

Characterization is performed using x-ray diffraction (XRD) to analyze crystal structure and phase purity, field-emission scanning electron microscopy (FE-SEM) to examine surface morphology and layer uniformity, and UV-visible spectrophotometry to record the absorption spectra of the prepared structures. The optoelectronic response is measured by exposing the structure to a pulsed 550 nm laser and recording photocurrent generation, evaluating its potential for photodetection and light-harvesting applications.

3. Results and Discussion

Figure (2) shows the XRD patterns of CuO, NiO and CuO/NiO multilayer structures prepared by thermal evaporation. These patterns typically show distinct peaks corresponding to their monoclinic (CuO) and cubic (NiO) crystal structures. Peaks such as (111), (200), and (220) for NiO, and (110), (002), and (111) for CuO confirm phase purity and crystallinity, with sharp peaks indicating high-quality thin films.

Figure (3) shows the FE-SEM image of the CuO/NiO multilayer structures prepared in this work. The particle size of metal oxide nanostructures significantly influences their optical and optoelectronic properties. As the particle size decreases to the nanoscale, quantum confinement effects become prominent, leading to discrete energy levels and a widening of the bandgap. This results in a blue shift in the absorption and emission spectra, which can be exploited to tune the optical response for specific applications. Smaller nanoparticles also exhibit enhanced surface states and defects, which can act as trapping centers for charge carriers, affecting the recombination dynamics and overall device performance.

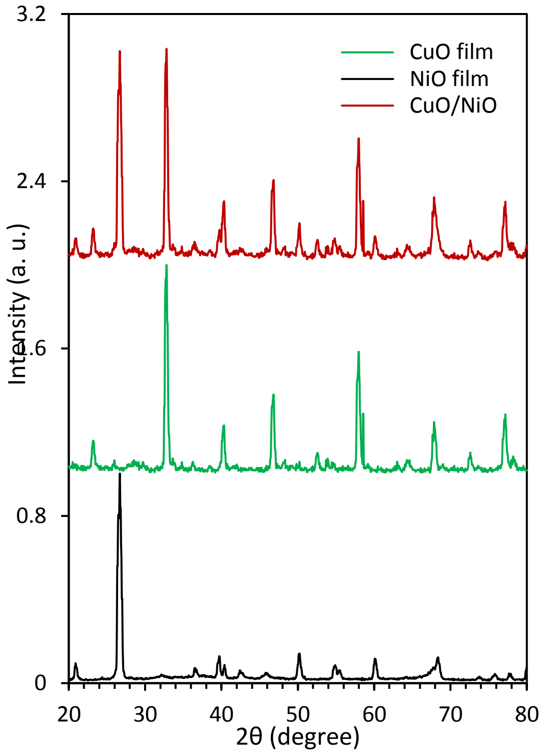

Fig. (2) XRD patterns of the CuO/NiO multilayer nanostructures prepared in this work

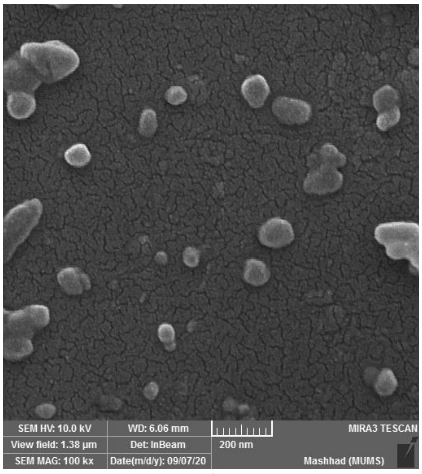

Fig. (3) FE-SEM image of the CuO/NiO multilayer nanostructures prepared in this work

However, careful control of particle size and surface passivation can mitigate these effects, leading to improved absorption, photoluminescence efficiency and charge carrier mobility. In optoelectronic devices, the reduced dimensionality of nanostructures facilitates faster charge transport and lower recombination rates, enhancing the overall efficiency and response time [29,30]. Figure (4) shows the absorption spectrum of the CuO/NiO multilayer structures prepared in this work, while figure (5) shows the effect of varying particle size of the CuO/NiO multilayer nanostructures on the optoelectronic response of these structures.

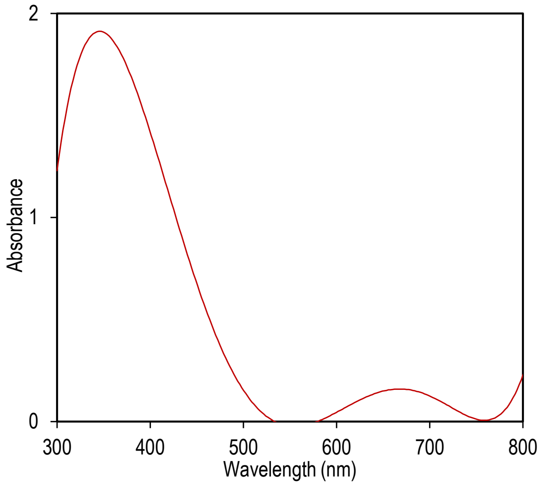

Fig. (4) Absorption spectrum of the CuO/NiO multilayer nanostructures prepared in this work

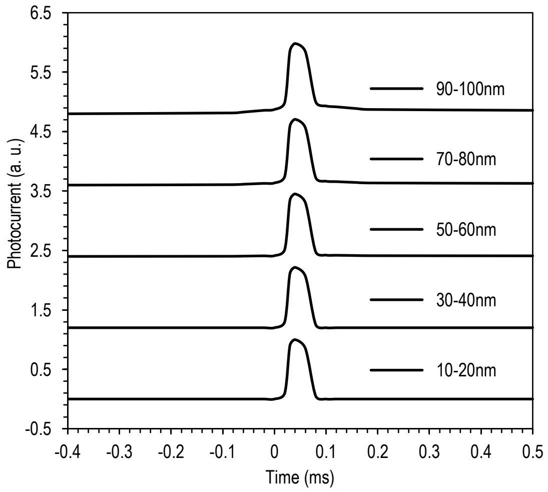

Fig. (4) Optoelectronic response of the CuO/NiO multilayer nanostructures prepared in this work

4. Conclusion

In concluding remarks, multilayer structures were fabricated from two semiconducting metal oxide (CuO and NiO) nanostructures on glass substrates by thermal evaporation method. The crystalline structure of the prepared multilayer structure was highly-pure as no materials other than CuO and NiO were found in the final sample. As well, the surface morphology of the prepared structure showed good distribution of uniformly-shaped particles with no clusters or aggregation. The optoelectronic response of the CuO/NiO/glass multilayer nanostructures was highly stable as the particle size of the used nanomaterials was ranging in 10-100nm.

References

[1] Y.S. Cho, K.H. Yoon, Dielectric ceramics, Ch. 5, H.S. Nalwa (ed.), **Handbook of Advanced Electronic and Photonic Materials and Devices**, Academic Press (2001), pp. 175-199.
[2] M. Li et al., Sens. Actuat. B Chem., 192 (2014) 261-268.
[3] J. Dhakshinamoorthy, J. Kulothungan, and V. Ramakrishnan, Metal oxide based bi/multilayer thin film heterostructures for gas sensing applications, Ch. 4, B.C. Yadav, P. Kumar (ed.), in **Metal Oxides**, Complex and Composite Metal Oxides for Gas, VOC and Humidity Sensors, Elsevier (2024), 91-132.
[4] G. Andermann, Appl. Surf. Sci., 31(1) (1988) 1-41.
[5] T.-H. Kim et al., Sens. Actuat. B Chem., 301 (2019) 127140.
[6] P.C. Maity and I. Lahiri, Diamond Related Mater., 139 (2023) 110339.
[7] A. Sun et al., Int. J. Hydro. Energy, 47(39) (2022) 17494-17503.
[8] G. Yang et al., Colloids Surf. A Physicochem. Eng. Aspects, 659 (2023) 130813.
[9] D. Yadav et al., J. Sci. Adv. Mater. Dev., 9(4) (2024) 100813.
[10] I. Lee et al., J. Taiwan Inst. Chem. Eng., 157 (2024) 105405.
[11] S. Samantaray et al., J. Energy Storage, 99(A) (2024) 113330.
[12] K. Uchino, “Multilayer Technologies for Piezoceramic Materials”, Ch. 11, K. Uchino (ed.), in Advanced Piezoelectric Materials (2nd ed.), Woodhead Publishing (2017), pp. 423-451.
[13] A.R. Patil et al., Mater. Today Commun., 34 (2023) 105356.

[14] K. Lim et al., Sens. Actuat. B Chem., 348 (2021) 130665.
[15] S. Gupta and N.-H. Tai, J. Taiwan Inst. Chem. Eng., 154 (2024) 104957.
[16] G.N. Starostin et al., Int. J. Hydro. Energy, 97 (2025) 891-903.
[17] K. Suga et al., Sens. Actuat. B Chem., 14 (1–3) (1993) 598-599.
[18] W. Guo, W. Sun, and Y. Wang, ACS Nano, 9(11) (2015) 11462–11471.
[19] A. Bolder, Nanomed. Res. J., 13(1) (2022) 11–18.
[20] J. Smith and L. Johnson, Sci. Rep., 8 (2018) 36378.
[21] M. Lee and K. Patel, Mater. Res. Innov., 24(3) (2024) 2363733.
[22] R. Kumar and S. Gupta, J. Mater. Sci., 59(2) (2024) 373525388.
[23] V. Constantoudis et al., Micro Nano Eng., 16 (2022) 100148.
[24] L.I. Ibarra-Rodriguez et al., J. Mater. Res. Technol., 26 (2023) 137-149.
[25] E.F. Abo Zeid et al., J. Mater. Res. Technol., 9(2) (2020) 1457-1467.
[26] S.G. Krishnan et al., J. King Saud Univ. Sci., 34(1) (2022) 101718.
[27] G.S. Sree et al., Arabian J. Chem., 13(4) (2020) 5137-5150.
[28] E. Arulkumar and S. Thanikaikarasan, Chem. Phys. Impact, 7 (2023) 100350.
[29] E. Arulkumar, S. Shanthosh Shree and S. Thanikaikarasan, Results Chem., 6 (2023) 101087.
[30] Y. Wu et al., Chinese Chem. Lett., 34(1) (2023) 107480.